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Walton 2 Interpretive Summary

Middle Velkerri – Lower Velkerri Interval

As a part of:
Northern Territory Geological Survey - Australia
McArthur Basin Integrated Petroleum Geochemistry, 2016

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June 29, 2016

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

PETROLEUM GEOCHEMISTRY

INTRODUCTORY NOTE

A geochemical investigation has been conducted to assess hydrocarbon prospectivity of the Middle and Lower Velkerri Formations in the Walton 2 well located in the Beetaloo Sub-Basin, Northern Territories, Australia. Seven (7) core chip samples from this well were analyzed by a variety of geochemical techniques, including total organic carbon (TOC, LECO®) and programmed pyrolysis (SRA). In addition, client supplied published geochemical data for 96 samples was also incorporated into the interpretive evaluation. The complete results of these analyses are documented in this report along with an integrated geochemical interpretation that is summarized in the following table.

Well Name	*Formation*	*Main Product*	*Thermal Maturity*	*Source Rock Richness*	*Organic Matter Type*	*Shale Oil Risk*
Walton 2	Middle Velkerri	**Estimated Original →**		Excellent (7.15% TOC)	Oil-prone Type II	Moderate
Measured Currently →		Oil	Early Oil Window	↓ Excellent (6.36% TOC)	↓ Oil-prone Type II	
Walton 2	Lower Velkerri	**Estimated Original →**		Good (1.19% TOC)	Oil-prone Type II	High
Measured Currently →		Oil	Early Oil Window	↓ Fair (0.90% TOC)	↓ Gas-Prone Type III	

Current TOC averages represent all data available; Original TOC averages are only high graded samples that have PPy data

Table 1. Geochemical Summary

MIDDLE VELKERRI FORMATION

Six samples (6) from the Middle Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (58 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.20 to 11.71 wt.% and averaged 6.36 wt.% (excellent). All but one of these samples have TOC contents above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, while fifty-one (51) samples have TOC content above the minimum requirement of 2 wt.% for *economic* petroleum source rocks. Highest TOC contents tend to occur in the upper half of the designated Middle Velkerri interval, between 265−423 m depth (Fig. 1). There are three distinct cycles of TOC within the Middle Velkerri with maxima occurring at depths of 336.10, 476.35 and 531.65 m (Fig. 1). These three organic rich intervals have been previously recognized within the Middle Velkerri (Lanigan et al, 1994) and could be associated with the base of transgressive systems tracts (TST) in a series of platform/ramp parasequences (Bohacs et al., 2013). These stepwise changes in TOC and corresponding minimal change in Hydrogen Index values (HI) suggests that production was the major control on organic richness along with auto-dilution by pelagic carbonate (Bohacs et al., 2013).

The S1 values of the Middle Velkerri source rock samples average 2.92 mg HC/g rock (64 bbl oil/acre-ft) and S2 values average 29.27 mg HC/g rock (641 bbl oil/acre-ft). The S1 and S2 values imply very good in-situ hydrocarbon saturation and excellent remaining generative potential, and like TOC the highest values are found in the upper section of this interval (Fig. 1). The normalized oil content (NOC) in the Middle Velkerri samples, (S1/TOC) x 100, averages 45 (Fig. 1). NOC values of 20 to 50 are typical of low maturity source rocks, whereas values of 50 to 100 indicate possible oil staining or shows in thermally mature, tight petroleum source rocks. NOC > 100 are often associated with conventional oil reservoirs and indicate good prospectivity in unconventional shale oil plays. Jarvie (2012) has utilized a depth comparison of TOC versus programmed pyrolysis S1 yields as a potential indicator of producible hydrocarbon saturation in unconventional source rocks. When the S1 yields (reported as mg HC/g rock) exceed or “cross-over” the measured TOC content (reported as wt.%), this would be interpreted to

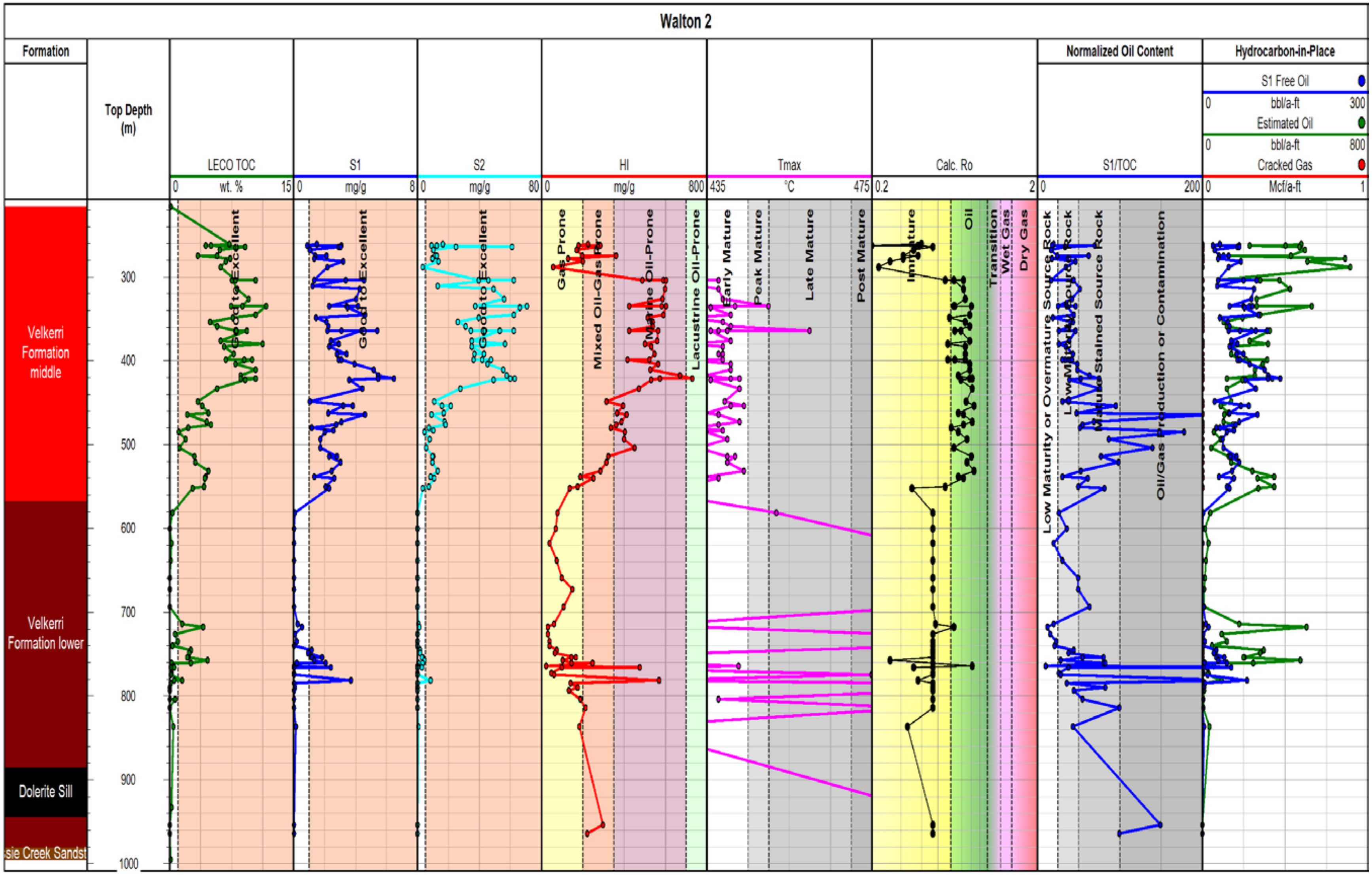

Figure 1. Geochemical depth plots for the Walton 2 well.

represent zones with good potential for containing producible hydrocarbon saturation (or zones of possible contamination). In the present study, S1 crosses over TOC in only three samples between the interval of 421.2−505.2 m (Fig. 1) in the Middle Velkerri Formation.

Measured Hydrogen Index (HI) values in the Middle Velkerri average 418 mg HC/g TOC, indicating oil-prone Type II kerogen quality in these source rocks at present day. This is somewhat higher compared with elemental analyses of two select kerogen samples from the Middle Velkerri that have average H/C ratios of 1.07, which would indicate more of a mixed Type II/III kerogen (max. H/C is 1.37; Type II). Depth trends show elevated HI values are found in the main source rock interval between 304−505 m, where TOC values are also highest (Fig. 1). Original HI_o of these samples are estimated to average 550 mg HC/g rock, which also indicate oil-prone Type II kerogen and suggests that thermal maturity levels are moderate. Transformation Ratios (TR) based upon HI average only 39%, which is consistent with an immature to very early oil window thermal maturity. T_{max} values in the Middle Velkerri samples average 433°C. T_{max} between 425 and 435°C typically indicate early oil window, while values < 425°C are considered immature with regard to the oil window (Type II kerogen). On the basis of these guidelines, the average Middle Velkerri T_{max} values in this well would be interpreted to be in the early oil window. Using the formula published by Jarvie et al. (2007) for Type II kerogen (Calculated $R_o = (0.0180)(T_{max}) - 7.16$), the average measured T_{max} value of 433°C is equivalent to a Calc. $\%R_o$ value of 0.64%. It is important to note that T_{max} is only a crude measure of thermal maturation (Peters, 1986) and it can be compromised by a variety of pyrolysis artifacts and caveats. Additional support for this interpreted thermal maturity comes from aromatic biomarker ratios examined using core slice experiments (471 m sample depth), which give a range of calculated reflectance values from 0.48 to 0.70% R_o (Flannery and George, 2014).

Production Index (PI) values in these Middle Velkerri samples average 0.13. These moderate PI values are consistent with source rocks in the early oil window, which typically have PI values between ~0.10 to 0.15. Samples in the peak oil window tend to have elevated PI values in the range of 0.15 to 0.25, which is more consistent with higher in-situ hydrocarbon saturations.

LOWER VELKERRI FORMATION

One sample (1) from the Lower Velkerri Formation was analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (33 samples) composed of client supplied public data (Fig. 1). The Lower Velkerri Formation in the Walton 2 well exhibits fair generative potential for petroleum source rocks based on TOC content values (Fig. 1). TOC content ranges from 0.02 to 4.62 wt.% and averages 0.90 wt.% (fair). Seven (7) samples analyzed exceed the minimum value of 2.0 wt.% for *economic* petroleum source rocks (Lewan, 1987) and the majority of the samples have < 0.5 wt.% TOC and would be considered non-source rocks. There is a single zone of elevated TOC with two maxima between 714.6−761.7 m (Fig. 1).

The S1 values in the Lower Velkerri average 0.53 mg HC/g rock (12 bbl oil/acre-ft), indicating generally poor in-situ hydrocarbon saturation (Fig. 1). There are occasional high S1 values up to 3.75 mg HC/g rock (82 bbl oil/acre-ft), but these are sporadic and appear to be associated in many instance with elevated HI values suggesting they could be contamination. Flannery and George (2014) examined a core sample from the Walton 2 well (471 m depth) using slice experiments and determined that the exterior of the core was exposed to contamination from both the drilling and sawing processes. Thus, S1 values should be used cautiously when evaluating hydrocarbon saturation in the Walton 2 well.

NOC values in the Lower Velkerri interval are overall slightly higher in comparison to the overlying strata and average 58. Oil cross over (NOC > 100) was observed only in a few samples near the base of this interval and the sporadic nature of these suggest possible contamination (Fig. 1), which suggests possible producible hydrocarbons at these depths. The S2 values in this interval average 1.15 mg HC/g rock (25 bbl oil/acre-ft), which indicates poor remaining generative potential.

Measured HI values in the Lower Velkerri samples average 141 mg HC/g TOC, which indicate mostly gas-prone Type III kerogen quality in these source rocks at present day. Estimated original HI_o values in these samples average 459 mg HC/g TOC, which indicate oil-prone Type II kerogen quality. Transformation Ratios (TR) based upon HI average 79%, which is somewhat elevated for an interpreted early oil window thermal maturity. This could be a consequence of assuming too high of an original HI_o values for these samples and may suggest somewhat lower original kerogen quality than presumed on the basis of published literature data (Law et al., 2010; Crick et al., 1988; Taylor et al., 1994).

The organic-matter in the Lower Velkerri interval in the Walton 2 well is thermally mature and is interpreted to be in the early oil window. Programmed pyrolysis T_{max} values average only 424°C (Fig. 1). Using the formula published by Jarvie et al. (2007) for Type II kerogen (Calculated R_o = (0.0180)(T_{max}) – 7.16), the average measured T_{max} value of 424°C is equivalent to a Calc. %R_o value of 0.47%. It is important to note that T_{max} is only a crude measure of thermal maturation (Peters, 1986) and it can be compromised by a variety of pyrolysis artifacts and caveats, which is especially true in samples that may have been affected by drilling mud contamination. The early oil window thermal maturity interpretation for the Lower Velkerri interval is based more upon the relationship with the overlying unit in which Tmax and biomarker data confirm maturity assessment and on documented oil saturation within this interval.

It is also of interest to note that a dolorite sill was noted near the base of the Lower Velkerri formation in the Walton 2 well at a depth of 934 m. A localized heating event initiated by dolerite sill emplacement has been proposed to potentially explain anomalous high thermal maturity levels within this interval (Taylor et al. 1994) for well locations in the northwest portion of the Beetaloo Sub-basin. In the case of the Walton 2 well there is no conclusive evidence from Tmax data or other maturity related geochemical ratios to suggest that this has had any impact on thermal maturity.

Production Index (PI) values in these Lower Velkerri samples average 0.30. These elevated PI values are consistent with source rocks in the mid- to late oil window. The PI values are consistently elevated throughout the Lower Velkerri interval and do not appear to correlate with zones where NOC values are also highest.

The thermal maturity of the Lower Velkerri source was also evaluated by measured Kübler Index values from XRD, which are based upon illite crystallinity. These values can be used as maturity indicator when samples contain sufficient high quality clays (Abad, 2008). A single sample (764.55 m) from the Lower Velkerri (60% clays) has a measured Kübler Index of 0.277, which is equivalent to a measured vitrinite reflectance of > 4% (late stage metagenesis). This interpretation is inconsistent with other geochemical maturity ratios evaluated in this study and suggests the Kübler Index should be used with caution to evaluate thermal maturity in Mesoproterozoic aged source rocks.

ORIGINAL GENERATIVE POTENTIAL AND HYDROCARBON YIELD CALCULATIONS

Petroleum generative capacity depends on the original quantity of organic matter (TOC_o) and the original type of organic matter (HI_o) (Peters et al., 2005, p. 97). The petroleum generation process has likely decreased the remaining generative potential as measured by TOC_{pd} and HI_{pd} in the Velkerri source rock samples examined in this study. We can estimate the extent of the petroleum generation process, the volume of expelled oil and the expulsion efficiency by making some reasonable assumptions based on the core geochemical data and published regional information (Jarvie et al., 2007; Peters et al., 2005).

HI_o values can be computed from visual kerogen assessments and assigned kerogen-type HI_o average values using the following equation (Jarvie et al., 2007):

$$HI_o = \left(\frac{\%\text{Type I}}{100}\times 750\right)+\left(\frac{\%\text{Type II}}{100}\times 450\right)+\left(\frac{\%\text{ Type III}}{100}\times 125\right)+\left(\frac{\%\text{Type IV}}{100}\times 50\right) \qquad (1)$$

This equation requires the input of maceral percentages from visual kerogen assessment of a source rock. For the present study, only limited kerogen data were available. Where available, these kerogen data sets were used. In the absence of other measured kerogen data original kerogen type were interpreted in the context of measured present day TOC, HI and OI values to arrive at an appropriate kerogen mix for each sample examined in this investigation. All samples were modeled using appropriate kerogen mix to maintain an appropriate transformation ratio consistent with the interpreted thermal maturity. The average maceral percentage in the various formations evaluated in the current study are shown in Table 2, along with the resultant average original HI_o values calculated using equation (1) above. The kerogen estimations used in this study are generally in agreement with other published values that suggest Type II to a mixed Type I/II kerogen assemblage (Law et al., 2010; Crick et al., 1988; Taylor et al., 1994).

Formation	%Type I 750 HI_o	%Type II 450 HI_o	%Type III 125 HI_o	%Type IV 50 HI_o	HI_o
Middle Velkerri	33	67	0	0	550
Lower Velkerri	3	97	0	0	459

Table 2. Average Kerogen Estimations for Walton 2 well.

The extent of the petroleum-generation process, or transformation ratio (TR) which is also called fractional conversion, is calculated as follows (Jarvie et al., 2007, p. 497):

$$TR_{HI} = 1 - \frac{HI_{pd}\left[1200 - HI_o\left(1 - PI_o\right)\right]}{HI_o\left[1200 - HI_{pd}\left(1 - PI_{pd}\right)\right]} \quad (2)$$

HI_{pd} and PI_{pd} are the measured HI and PI values for the various source rock samples in this well. The average HI_{pd} and PI_{pd} for the formations evaluated in the current study are shown in Table 3. HI_o and PI_o are the original HI and PI values for immature organic matter in the rocks. For this calculation using the assumptions described previously results in an average HI_o values ranging from of 459 to 550 mg HC/g TOC (Table 2). We assume a PI_o of 0.02 (see Peters et al., 2005). Using these values in equation 2, the extent of fractional conversion of HI_o to petroleum varies from 0.39 to 0.79 (Table 3), i.e., on average an estimated 39 to 79% of the petroleum generation process has been completed.

The original TOC_o in the source rocks before burial and thermal maturation is constrained by mass balance considerations as follows (corrected from Jarvie et al., 2007):

$$TOC_o = \frac{HI_{pd}\left(\frac{TOC_{pd}}{1+k}\right)(83.33)}{\left[HI_o\left(1 - TR_{HI}\right)\left(83.33 - \left(\frac{TOC_{pd}}{1+k}\right)\right)\right] + \left[HI_{pd}\left(\frac{TOC_{pd}}{1+k}\right)\right]} \quad (3)$$

In this equation k is a correction factor based on residual organic carbon being enriched in carbon over original values at high maturity (Jarvie et al., 2007, p. 497). For Type II kerogen the increase in residual carbon C_R at high maturity is assigned a value of 15% (whereas for Type I, it is 50%, and for Type III, it is 0%) and the correction factor k is then $TR_{HI} \times C_R$. The kerogen mix for each individual sample was used in this calculation.

Using equation 3, the average estimated original TOC_o for the source rock samples in this well before petroleum generation varies from 1.19 to 7.15 wt.% (Table 3).

The original generation potential $S2_o$ can be calculated using the following equation:

$$S2_o = \left(\frac{HI_o \times TOC_o}{100}\right) \quad (4)$$

For the Velkerri source rocks examined in the Walton 2 well, the average $S2_o$ values vary from 5.5 to 41.0 mg HC/g rock or approximately 120 to 898 bbl/acre-ft (multiply $S2_o$ by 21.89 to calculate barrels/acre-ft, Jarvie and Tobey, 1999) (Table 3).

Knowing the measured remaining generation potential S2 from programmed pyrolysis and using the calculated original generation potential $S2_o$ enables a determination of the amounts of hydrocarbons generated. A VR_o algorithm can then be applied to estimate fractional oil cracking thereby converting yields to estimated oil and cracked gas (reported as Mcf/acre-ft or thousand cubic feet/acre-ft).

$$\text{Original } (S2_o) - \text{Remaining } (S2) = \text{Generated HCs} \quad (5)$$

Using this methodology for the Middle Velkerri samples analyzed in the current study, the generated oil yields average 257 bbl/acre-ft. The generated oil yield from overlying Lower Velkerri was lower with an average value of only 95 bbl/acre-ft.

Formation	TOC_{pd}	HI_{pd}	$S2_{pd}$ bbl/a-ft	HI_o	TR	TOC_o	$S2_o$ bbl/a-ft	S1 Free Oil bbl/a-ft	Est. Oil bbl/a-ft	Cracked Gas Mcf/a-ft
Middle Velkerri	6.48	418	641	550	0.39	7.15	898	64	257	0
Lower Velkerri	0.91	141	25	459	0.79	1.19	120	12	95	0

Table 3. Hydrocarbon Yields average data for Walton 2 well.

The amount of hydrocarbons (oil + gas) expelled from the rocks can be estimated as the difference between the amount of residual oil measured via programmed pyrolysis (S1) and the amount of estimated generated hydrocarbon yields determined above (equation 5). The expulsion efficiency (ExEf) can then be calculated as a direct proportion of the measured retained oil saturations and the average generated hydrocarbon yields. Thus, the resulting expulsion efficiency for the Velkerri intervals varies from 75% in the Middle unit to 88% in the Lower interval.

The Middle and Lower Velkerri source rock intervals in the Walton 2 well are interpreted to be in the early oil window and hydrocarbon yield calculations suggest minor to significant amounts of generation have occurred (predominantly oil with some presumed associated gas). From an exploration risk perspective, this is generally favorable. However, it is useful to relate these hydrocarbon yields to other productive unconventional US Shale plays (Table 4). In doing so, the potential critical value is not necessarily the generated oil and gas yields, but also the original ($S2_o$) generation potential of the source rocks. These values related to the ultimate volumes of hydrocarbon that could be generated at depth in the basin. For the Middle Velkerri original generation potential ($S2_o$) averages 898 bbl oil/acre-ft, this is higher than any of the other formations on the list of unconventional US Shale plays shown below. For the Lower Velkerri, original generation potential is much lower at only 120 bbl oil/acre-ft and this unit does not compare favorably with other unconventional US Shale plays.

Sample Database Averages TOC >1%	HI° mg/g TOC	TR	TOC° wt%	S2° mg/g Rock	Remaining Potential bbl/a-ft	Original Potential bbl/a-ft	Oil Cracked %	S1 Free Oil bbl/a-ft	Estimated Oil bbl/a-ft	Cracked Gas Mcf/a-ft
Barnett Shale Ft. Worth Basin	435	0.84	5.38	23.40	94	513	0.40	33	251	1005
Barnett Shale Delaware Basin	435	0.91	5.25	22.84	52	500	0.80	32	90	2149
Woodford Shale Delaware Basin	480	0.89	6.41	30.79	139	674	0.89	46	60	2854
Haynesville Shale E. Texas Basin	400	0.98	3.93	15.73	7	344	1.00	3	0	2022
Fayetteville Shale Arkoma Basin	435	0.95	3.34	14.53	15	318	1.00	10	0	1820
Woodford Shale Arkoma Basin	520	0.87	5.15	26.80	12	587	0.70	87	170	2431
Eagle Ford Shale Gulf Coast Basin	520	0.85	3.19	16.61	61	364	0.47	22	161	848
Marcellus Shale Appalachian Basin	600	0.97	6.44	38.66	34	847	1.00	24	0	4875
Utica Shale Appalachian Basin	450	0.98	2.74	12.32	6	270	1.00	12	0	1585
Barnett Shale Oil	450	0.47	5.47	24.64	326	540	0.00	79	213	0
Barnett Shale Gas	450	0.96	5.58	25.13	23	550	0.87	7	68	2751
Middle Velkerri	550	0.39	7.15	40.99	641	898	0.00	64	257	0
Lower Velkerri	459	0.79	1.19	5.50	25	120	0.00	12	95	0

Table 4. Geochemical Properties and Generation Potential for US Shale plays and current study.

HYDROCARBON SATURATIONS

A comparison was made between oil saturations based upon shale rock properties (SRP) analyses and those determined via programmed pyrolysis for a single sample from the Middle Velkerri Formation (400 m depth) in the Walton 2 well. In this instance the measured SRP oil saturations are slightly higher than those determined by SRA methods using the S1 yields. The saturation determined by SRP was 4.39 mg oil/g AR Rock (96 bbl oil/acre-ft), while that determined from S1 yields on the same sample is 3.11 mg oil/g AR Rock (68 bbl oil/acre-ft). This suggests that the S1 is slightly underestimating the total hydrocarbons extracted using Dean-Stark methods (toluene). The likely cause of this is undoubtedly related to the in-situ hydrocarbon saturation, which is considered to be relatively low thermal maturity (early oil window). Low maturity oils generally contain relatively high abundances of non-volatile polar and asphaltene components associated with the in-situ oil/bitumen saturation. Further evaluation of the extractable hydrocarbons by liquid chromatography and gas chromatography is warranted to fully evaluate the nature of these apparent discrepancies between SRP and S1 saturations.

UNCONVENTIONAL OIL & GAS RISK ASSESSMENT

The Mesoproterozoic Velkerri Formation source rocks in the Walton 2 well have been evaluated for unconventional oil and gas potential. These source rock samples are presented in a modified geochemical risk assessment diagram (Fig. 2) based upon published results from the Barnett Shale in the Fort Worth Basin. The data illustrated in the star plot represents average values for three of the four diagnostic ratios (no measured R_o data available). Also shown are the recommended areas for unconventional oil (in green) and gas (in red). Data that lies above the minimum threshold and within the shaded areas indicates samples with low geochemical risk for either thermogenic oil or gas production. Data that lie below the minimum threshold and fall in the immature region (in gray) indicate a high risk for commercial shale oil or gas production. Transformation ratios (TR) were calculated based upon HI_o estimates using measured and interpreted fractional composition of kerogen macerals.

The Middle Velkerri source rock interval in the Walton 2 well is interpreted to represent a moderate geochemical risk for in-situ shale oil production. The average TOC content of 6.36 wt.% is above the generally accepted minimum value of 1% TOC to be considered an *effective* source rock for hydrocarbon generation/expulsion (Fig. 2). It is also well above the minimum requirements of 2 wt.% for *economic* petroleum source rocks. Original organic matter type is interpreted to be predominantly oil-prone Type II marine algal kerogen. Thermal maturity parameters from programmed pyrolysis place the Middle Velkerri source interval in early oil window. The average Tmax value of 433°C is just below the recommended minimum value of 435°C for shale oil and well below the minimum of 455°C for shale gas (Fig. 2). This amount of conversion would likely be sufficient to generate/expel minor to significant amounts of hydrocarbons from this organic-rich, oil prone source facies. Transformation Ratios (TR), the least constrained risk parameter, average 24% and fall below the recommended minimum of 50% for shale oil systems (Fig. 2). On the basis of all of these measured geochemical risk parameters, the Middle Velkerri source interval would be considered a moderate risk for shale oil and a high risk for shale gas since all of the thermal maturity risk parameters do fall below recommended minimum thresholds (Fig. 2). Aromatic biomarker thermal maturity parameters reported for this interval (Flannery and George, 2014) in the Walton 2 well provide an independent confirmation of early oil thermal maturity and potentially mitigate the risk assessment to some degree.

The other formation examined in the current study is considered to represent high risk for in-situ shale oil/gas production. This is primarily related to organic richness, although additional factors also need to be considered. The Lower Velkerri samples have an average TOC of 0.90 wt.% and thermal maturity indicators suggest early window maturity. On the risk assessment diagram, average Tmax value of 424°C is below the recommended minimum value of 435°C for shale oil, but the Transformation Ratio of 70% is above the minimum threshold (Fig. 2). For these reasons, the Lower Velkerri interval is considered to be high risk for commercial shale oil development and is also a high risk for shale gas.

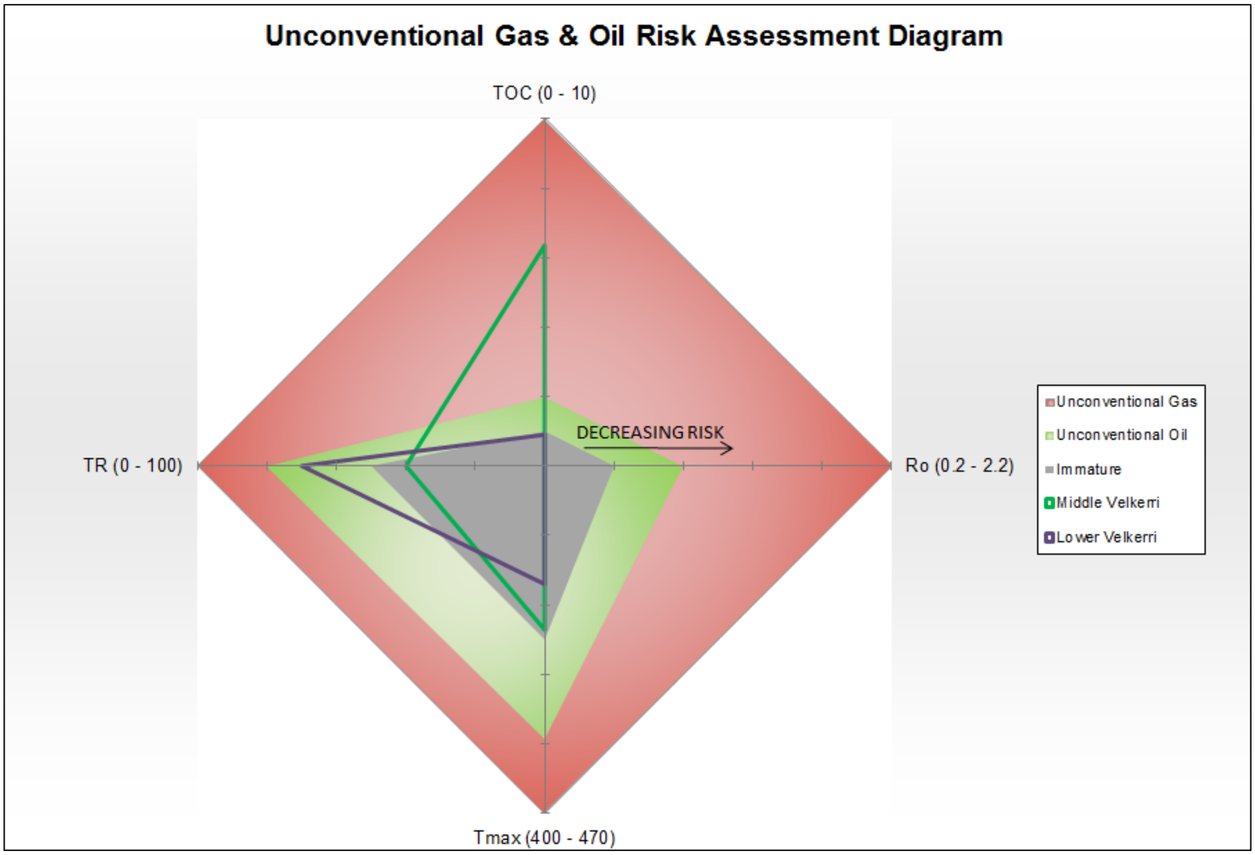

Figure 2. Geochemical Risk Assessment diagram for Mesoproterozoic Velkerri Formation source rocks in the Walton 2 well.

In the Middle Velkerri source interval, measured in-situ oil saturation determined by programmed pyrolysis S1 yields is very good (avg. 64 bbl oil/acre-ft), suggesting low risk for shale oil development (Fig. 3). This is also supported by the high in-situ hydrocarbon saturations determined from SRP analysis (96 bbl oil/acre-ft), although this single sample may not be representative of the entire interval. Hydrocarbon yield calculations on as-received samples show estimates of average generated oil from the Middle Velkerri at 257 bbl oil/acre-ft. As a comparison, a representative example from the core area of Barnett Shale oil production in the Fort Worth Basin has an estimated generated oil yield of 213 bbl/a-ft with a measured in-situ oil saturation of 79 bbl/a-ft. These values are comparable to the Middle Velkerri and minor differences could be due to differences in thermal maturity (Barnett Shale oil example is at a peak oil widow maturity of 0.86% VR_o).

In the Lower Velkerri source interval measured in-situ oil saturation from S1 yields is generally poor (avg.12 bbl oil/acre-ft), but estimated generated oil yields are moderate (avg. 95 bbl oil/acre-ft) due to the presence of a few samples with elevated organic richness (Fig. 3). While these average generated oil yields may seem somewhat attractive, they are apparently not representative of the overall potential of the unit and could even be compromised by potential contamination issues.

It is important to note that the quantity of oil generated from a potential source rock is only one geochemical factor to consider in regard to risk assessment. Equally important is the quality of the oil generated, since this factor can be a critical element in assessing the movability and ultimate recovery. The interpreted thermal maturity of the Middle and Lower Velkerri source intervals in this well is in the early oil window and hydrocarbon saturation is likely to be moderately heavy. The presence of heavy oil and/or bitumen could also indicate a source interval with restricted microporosity. Such microporosity is considered necessary for recovery of in-situ oil saturation and can be better assessed using scanning electron microscopy (SEM). Source rock extract fingerprints and bulk fractional compositional analyses from select Velkerri samples would also aid in the determination of the quality of the in-situ hydrocarbon saturation and provide a better assessment of their movability and ultimate recovery potential.

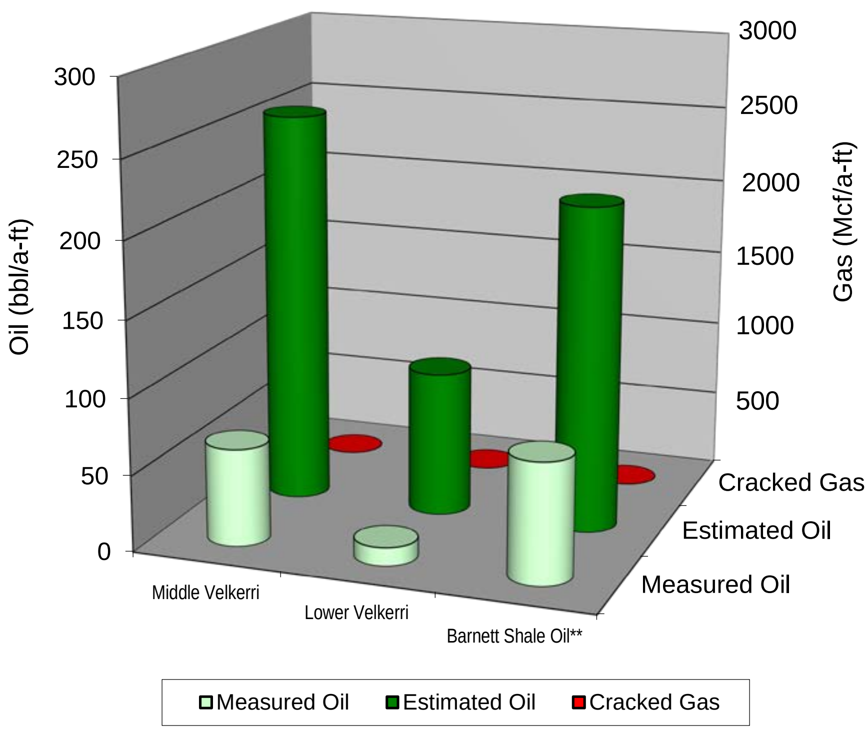

Figure 3. Hydrocarbon yield estimates for the Mesoproterozoic source rocks in the Walton 2 well compared to Barnett Shale in the oil window.

GEOCHEMICAL SUMMARY

The Middle Velkerri source interval in the Walton 2 well is interpreted to represent moderate geochemical risk for unconventional shale oil development. It clearly has elevated organic richness (avg. 6.36 wt.% TOC) and is considered an excellent source rock with dominantly oil-prone Type II kerogen. Thermal maturity parameters indicate that the source interval is in the early oil window, 0.64% Calc. R_o, but key risk ratios are slightly below recommended minimum thresholds for shale oil systems. The Middle Velkerri has likely generated significant amounts of oil (avg. 257 bbl oil/acre-ft) and comparison to other systems such as the Barnett Shale show in-situ oil saturations are generally comparable. Risk criteria like the S1 versus TOC show oil cross-over for only a few samples in the upper portion of this unit between the depths of 421−505 m. Further evaluation of in-situ oil characteristics would be required to fully evaluate potential oil mobility and recovery risk.

The Lower Velkerri source rock interval evaluated in the Walton 2 well generally has higher risk in comparison to the Middle Velkerri. This horizon has marginal organic richness, with the average 0.90 wt% TOC being below the minimum threshold for shale oil. The estimated generated oil is moderate in the Lower Velkerri, but this may be skewed by sampling bias and measured in-situ oil saturation is low.

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Appendix I

Hydrocarbon Yield Calculation
Beetaloo Sub-Basin Group
Walton 2

McArthur Basin Integrated Petroleum Geochemistry, 2016

Northern Territory Geological Survey - Australia

Weatherford® LABORATORIES

Walton 2

Hydrocarbon Yield Calculation

Sample	Top Depth	TOC*	HI*	S1*	S2*	Calc.Ro	PI*	%Type IV 50 HIº	% Type III 125 HIº	%Type II 450 HIº	%Type I 750 HIº	HIº	TR	TOCº	S2º	S2 (meas) Remaining Potential	S2 (orig) Original Potential	Oil Cracked	S1 Free Oil	Estimated Oil	Cracked Gas
Walton 2	(m)	wt%	mg/g TOC	mg/g Rock	mg/g Rock	%						mg/g TOC		wt%	mg/g Rock	bbl/a-ft	bbl/a-ft	%	bbl/a-ft	bbl/a-ft	Mcf/a-ft
	261	7.30	226	1.51	16.51	**0.40**	0.08	0	0	100	0	450	0.62	8.53	38.39	362	841	0.00	33	479	0
HD14DJR009	264	5.05	181	0.93	9.12	**0.20**	0.09	0	0	100	0	450	0.71	6.11	27.50	200	602	0.00	20	403	0
1416156	264	4.44	289	3.09	12.82	**0.38**	0.19	0	0	100	0	450	0.50	5.20	23.38	281	512	0.00	68	231	0
	265	9.13	276	3.07	25.19	**0.47**	0.11	0	0	100	0	450	0.51	10.39	46.74	552	1024	0.00	67	472	0
	269	6.10	174	1.05	10.59	**0.36**	0.09	0	0	100	0	450	0.72	7.38	33.20	232	727	0.00	23	495	0
	275	5.78	199	1.44	11.52	**0.31**	0.11	0	0	100	0	450	0.67	6.92	31.16	252	682	0.00	32	430	0
1416157	276	3.46	364	2.17	12.60	**0.38**	0.15	0	0	100	0	450	0.31	3.85	17.32	276	379	0.00	48	103	0
	279	7.40	130	1.33	9.64	**0.31**	0.12	0	0	100	0	450	0.80	9.14	41.13	211	901	0.00	29	690	0
	283	6.80	202	3.20	13.76	**0.26**	0.19	0	0	100	0	450	0.67	8.21	36.95	301	809	0.00	70	508	0
1416158	289	6.21	58	2.19	3.60	**0.22**	0.38	0	0	100	0	450	0.92	8.09	36.41	79	797	0.00	48	718	0
HD14DJR011	305	8.02	492	1.35	39.47	**0.56**	0.03	0	0	75	25	525	0.11	8.21	43.09	864	944	0.00	30	79	0
1416159	305	10.50	591	4.56	62.10	**0.72**	0.07	0	0	25	75	675	0.27	11.12	75.03	1360	1643	0.00	100	283	0
1329811	305	7.63	605	3.40	46.18	**0.63**	0.07	0	0	0	100	750	0.41	8.43	63.21	1011	1384	0.00	74	373	0
1416160	315	8.25	600	4.31	49.46	**0.72**	0.08	0	0	0	100	750	0.43	9.19	68.90	1083	1509	0.00	94	426	0
1416161	327	9.56	590	4.08	56.37	**0.74**	0.07	0	0	25	75	675	0.28	10.14	68.47	1235	1500	0.00	89	265	0
1329810	336	7.43	582	3.45	43.25	**0.63**	0.07	0	0	25	75	675	0.30	7.98	53.86	947	1179	0.00	76	232	0
2831942	336	8.83	425	2.30	37.50	0.64	0.06	0	0	75	25	525	0.31	9.45	49.60	821	1086	0.00	50	265	0
1416162	336	11.70	604	4.18	70.66	**0.80**	0.06	0	0	0	100	750	0.41	12.65	94.89	1547	2078	0.00	92	531	0
1416163	345	10.50	593	4.65	62.26	**0.78**	0.07	0	0	25	75	675	0.27	11.12	75.03	1363	1643	0.00	102	280	0
HD14DJR013	350	7.72	514	1.49	39.69	**0.59**	0.04	0	0	50	50	600	0.26	8.10	48.60	869	1064	0.00	33	195	0
1416164	355	4.89	540	2.15	26.43	**0.74**	0.08	0	0	50	50	600	0.21	5.19	31.15	579	682	0.00	47	103	0
1416165	360	5.79	540	2.28	31.27	**0.78**	0.07	0	0	50	50	600	0.21	6.12	36.70	685	804	0.00	50	119	0
2831943	365	8.12	427	2.20	34.70	0.64	0.06	0	0	75	25	525	0.30	8.69	45.64	760	1000	0.00	48	240	0
1416166	365	9.36	568	4.42	53.19	**0.69**	0.08	0	0	25	75	675	0.33	10.08	68.06	1165	1491	0.00	97	326	0
1416167	377	6.25	562	2.45	35.11	**0.78**	0.07	0	0	25	75	675	0.34	6.77	45.67	769	1000	0.00	54	231	0
	381	11.25	503	2.95	56.58	**0.58**	0.05	0	0	50	50	600	0.29	11.87	71.20	1239	1559	0.00	65	320	0
1416168	384	6.59	532	2.30	35.07	**0.74**	0.06	0	0	50	50	600	0.23	6.96	41.73	768	914	0.00	50	146	0
1416169	393	7.82	549	3.42	42.96	**0.74**	0.07	0	0	50	50	600	0.19	8.23	49.35	941	1081	0.00	75	140	0
1416170	400	6.89	525	2.95	36.15	**0.74**	0.08	0	0	50	50	600	0.25	7.35	44.08	792	965	0.00	65	174	0
HD14DJR015	400	9.12	525	3.11	47.86	**0.64**	0.06	0	0	50	50	600	0.24	9.62	57.69	1048	1263	0.00	68	215	0
	400	10.00	420	3.11	41.95	**0.58**	0.07	0	0	75	25	525	0.32	10.75	56.44	919	1236	0.00	68	317	0
1416171	404	8.03	565	3.96	45.34	**0.78**	0.08	0	0	25	75	675	0.34	8.71	58.81	993	1288	0.00	87	295	0
1416172	412	10.50	527	5.18	55.30	**0.78**	0.09	0	0	50	50	600	0.25	11.17	67.00	1211	1467	0.00	113	256	0
	419	8.61	672	5.47	57.84	**0.67**	0.09	0	0	0	100	750	0.29	9.26	69.48	1267	1522	0.00	120	255	0
	421	8.60	730	6.47	62.76	**0.78**	0.09	0	0	0	100	750	0.16	9.08	68.14	1374	1492	0.00	142	118	0
1416173	422	10.40	576	5.48	59.88	**0.81**	0.08	0	0	25	75	675	0.32	11.18	75.46	1311	1653	0.00	120	341	0
	423	9.19	535	3.60	49.13	**0.69**	0.07	0	0	50	50	600	0.22	9.68	58.09	1076	1272	0.00	79	196	0
1416174	433	5.82	475	4.45	27.66	**0.81**	0.14	0	0	75	25	525	0.22	6.32	33.19	606	727	0.00	97	121	0
HD14DJR017	450	3.43	317	1.07	10.87	**0.75**	0.09	0	0	100	0	450	0.41	3.85	17.32	238	379	0.00	23	141	0
1416175	454	4.03	398	3.85	16.03	**0.83**	0.19	0	0	100	0	450	0.24	4.48	20.14	351	441	0.00	84	90	0
	463	4.69	369	2.24	17.29	**0.67**	0.11	0	0	100	0	450	0.29	5.13	23.10	379	506	0.00	49	127	0
1416176	466	2.18	413	4.62	9.00	**0.72**	0.34	0	0	75	25	525	0.42	2.66	13.96	197	306	0.00	101	109	0
1416177	474	4.48	390	3.08	17.46	**0.81**	0.15	0	0	100	0	450	0.24	4.91	22.10	382	484	0.00	67	102	0
	476	5.04	363	2.77	18.29	**0.72**	0.13	0	0	100	0	450	0.31	5.56	25.03	401	548	0.00	61	148	0
HD14DJR019	481	2.29	336	1.20	7.69	**0.61**	0.13	0	0	100	0	450	0.38	2.58	11.63	168	255	0.00	26	86	0
1416178	485	1.14	404	2.03	4.60	**0.67**	0.31	0	0	75	25	525	0.43	1.38	7.26	101	159	0.00	44	58	0
1416179	495	1.99	400	1.73	7.96	**0.76**	0.18	0	0	75	25	525	0.40	2.30	12.06	174	264	0.00	38	90	0
1416192	505	1.27	452	1.78	5.74	**0.63**	0.24	0	0	75	25	525	0.31	1.47	7.72	126	169	0.00	39	43	0
1416180	515	3.01	324	2.32	9.76	**0.80**	0.19	0	0	100	0	450	0.42	3.47	15.63	214	342	0.00	51	129	0
1416181	521	3.09	317	3.06	9.80	**0.76**	0.24	0	0	100	0	450	0.44	3.63	16.32	215	357	0.00	67	143	0
1416182	532	4.72	285	2.51	13.47	**0.83**	0.16	0	0	100	0	450	0.50	5.48	24.64	295	540	0.00	55	245	0
	540	4.46	190	1.37	8.49	**0.67**	0.14	0	0	100	0	450	0.69	5.42	24.40	186	534	0.00	30	348	0
1416183	541	4.29	252	2.63	10.80	**0.72**	0.20	0	0	100	0	450	0.57	5.11	23.02	237	504	0.00	58	268	0
1416184	552	4.18	177	2.09	7.39	**0.56**	0.22	0	0	100	0	450	0.72	5.19	23.34	162	511	0.00	46	349	0
	553	2.80	137	2.29	3.83	**0.35**	0.37	0	0	100	0	450	0.79	3.62	16.30	84	357	0.00	50	273	0
Middle Velkerri (Avg)		**6.48**	**418**	**2.92**	**29.27**	**0.64**	**0.13**	**0**	**0**	**67**	**33**	**550**	**0.39**	**7.15**	**40.99**	**641**	**898**	**0.00**	**64**	**257**	**0**
	582	0.34	79	0.09	0.27	0.47	0.25	0	0	100	0	450	0.88	0.45	2.03	6	44	0.00	2	38	0
	601	0.11	73	0.04	0.08	0.47	0.33	0	0	100	0	450	0.89	0.15	0.66	2	14	0.00	1	13	0
	619	0.24	42	0.05	0.10	0.47	0.33	0	0	100	0	450	0.94	0.32	1.46	2	32	0.00	1	30	0
	639	0.16	75	0.05	0.12	0.47	0.29	0	0	100	0	450	0.89	0.21	0.96	3	21	0.00	1	18	0

Walton 2

Hydrocarbon Yield Calculation

																S2 (meas)	S2 (orig)				
Sample	Top Depth	TOC*	HI*	S1*	S2*	Calc.Ro	PI*	%Type IV 50 HI°	% Type III 125 HI°	%Type II 450 HI°	%Type I 750 HI°	HI°	TR	TOC°	S2°	Remaining Potential	Original Potential	Oil Cracked	S1 Free Oil	Estimated Oil	Cracked Gas
Walton 2	(m)	wt%	mg/g TOC	mg/g Rock	mg/g Rock	%						mg/g TOC		wt%	mg/g Rock	bbl/a-ft	bbl/a-ft	%	bbl/a-ft	bbl/a-ft	Mcf/a-ft
	660	0.12	100	0.06	0.12	0.47	0.33	0	0	100	0	450	0.85	0.16	0.71	3	16	0.00	1	13	0
	674	0.10	150	0.05	0.15	0.47	0.25	0	0	100	0	450	0.77	0.13	0.58	3	13	0.00	1	9	0
	695	0.11	109	0.07	0.12	0.47	0.37	0	0	100	0	450	0.84	0.15	0.65	3	14	0.00	2	12	0
	715	1.55	63	0.31	0.98	**0.49**	0.24	0	0	100	0	450	0.91	2.05	9.24	21	202	0.00	7	181	0
	718	4.11	34	0.55	1.41	**0.63**	0.28	0	0	100	0	450	0.95	5.44	24.49	31	536	0.00	12	505	0
	728	0.75	33	0.12	0.25	0.47	0.32	0	0	100	0	450	0.95	1.01	4.56	5	100	0.00	3	94	0
	736	0.98	43	0.23	0.42	0.47	0.35	0	0	100	0	450	0.94	1.32	5.94	9	130	0.00	5	121	0
	741	0.37	41	0.08	0.15	0.47	0.35	0	0	100	0	450	0.94	0.50	2.25	3	49	0.00	2	46	0
	746	2.60	75	1.16	1.94	0.47	0.37	0	0	100	0	450	0.89	3.44	15.46	42	339	0.00	25	296	0
	750	2.42	67	0.94	1.63	0.47	0.37	0	0	100	0	450	0.90	3.21	14.43	36	316	0.00	21	280	0
	755	2.29	166	1.84	3.81	0.47	0.33	0	0	100	0	450	0.74	2.92	13.15	83	288	0.00	40	205	0
	755	2.15	147	1.19	3.16	0.47	0.27	0	0	100	0	450	0.77	2.75	12.36	69	271	0.00	26	202	0
	759	4.62	105	1.35	4.83	**0.26**	0.22	0	0	100	0	450	0.84	5.91	26.58	106	582	0.00	30	476	0
	762	2.60	146	2.09	3.80	0.47	0.35	0	0	100	0	450	0.78	3.35	15.07	83	330	0.00	46	247	0
	762	0.24	250	0.20	0.60	0.47	0.25	0	0	100	0	450	0.58	0.29	1.32	13	29	0.00	4	16	0
HD14DJR021	765	0.45	25	0.05	0.11	**0.81**	0.31	0	0	100	0	450	0.96	0.61	2.74	2	60	0.00	1	58	0
	766	0.58	476	2.45	2.76	**0.36**	0.47	0	0	75	25	525	0.34	0.74	3.88	60	85	0.00	54	25	0
	767	0.21	100	0.08	0.21	0.47	0.28	0	0	100	0	450	0.85	0.28	1.24	5	27	0.00	2	23	0
	773	0.26	50	0.07	0.13	0.47	0.35	0	0	100	0	450	0.93	0.35	1.58	3	35	0.00	2	32	0
	776	0.21	62	0.06	0.13	0.47	0.32	0	0	100	0	450	0.91	0.28	1.27	3	28	0.00	1	25	0
	782	1.57	571	3.75	8.96	**0.38**	0.30	0	0	25	75	675	0.43	1.96	13.23	196	290	0.00	82	94	0
	785	0.14	143	0.05	0.20	0.47	0.20	0	0	100	0	450	0.78	0.18	0.81	4	18	0.00	1	13	0
	791	0.12	175	0.10	0.21	0.47	0.32	0	0	100	0	450	0.73	0.15	0.69	5	15	0.00	2	11	0
	794	0.09	133	0.04	0.12	0.47	0.25	0	0	100	0	450	0.80	0.12	0.52	3	11	0.00	1	9	0
	804	0.09	189	0.05	0.17	0.47	0.23	0	0	100	0	450	0.70	0.11	0.51	4	11	0.00	1	7	0
	815	0.06	217	0.06	0.13	0.47	0.32	0	0	100	0	450	0.65	0.08	0.34	3	7	0.00	1	5	0
	836	0.44	184	0.19	0.81	**0.33**	0.19	0	0	100	0	450	0.70	0.55	2.47	18	54	0.00	4	36	0
	954	0.02	300	0.03	0.06	0.47	0.33	0	0	100	0	450	0.49	0.02	0.11	1	2	0.00	1	1	0
	965	0.04	225	0.04	0.09	0.47	0.31	0	0	100	0	450	0.64	0.05	0.23	2	5	0.00	1	3	0
Lower Velkerri (Avg)		**0.91**	**141**	**0.53**	**1.15**	**0.47**	**0.30**	**0**	**0**	**97**	**3**	**459**	**0.79**	**1.19**	**5.50**	**25**	**120**	**0.00**	**12**	**95**	**0**
Barnett Shale Oil**		4.70	300	3.60	14.90	0.86	0.20	0	0	100	0	450	0.47	5.47	24.64	326	540	0.00	79	213	0
Barnett Shale**		4.21	26	0.33	1.07	1.66	0.24	0	0	100	0	450	0.96	5.58	25.13	23	550	0.87	7	68	2751

Notes: Calc.Ro values in **bold** are calculated from measured Tmax. Calc.Ro values in red font are intrepreted from other geochemical maturity data because Tmax was considered unreliable. All other Calc.Ro values are formation specific averages because Tmax was considered unreliable.

Kerogen Type in **bold** have visual kerogen data for estimates TR = Transformation Ratio (fractional conversion) (Original Potential - Remaining Potential) = (Estimated Oil + Cracked Gas)

Estimated Oil and Cracked Gas yield data assume complete conversion and no expulsion of hydrocarbon products and the proportion between each is based on empirical Ro calculated % cracking.

Yields do not represent recoverable products and are intended primarily for comparison purposes, yield calculations based on carbon mass balance are likely to be overestimations. **Estimated parameters for productive Barnett Shale in the Ft. Worth Basin

Hydrocarbon yield calculations and formulas are fully documented in the appendix section of Jarvie et al. (2007)

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